

Eye-tracking and Protocol Analysis of Expertise in Air Traffic Control Situation Awareness

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Abstract

Analyses of eye tracking and think-aloud protocol data were performed to examine novice-expert differences in perceptual and cognitive aspects of air traffic controllers' situation awareness. In Experiment 1, participants were asked to perceive situations that were manipulated by situation complexity. In Experiment 2, protocol analysis was performed to extract different task models and strategy models as a function of expertise. Then delayed-recall task and interviews about air control plans for the recalled situations were also executed. Results showed that expert controllers concentrate only on several critical features and have their own strategies to reduce mental workloads.

Introduction

This research focused on novice-expert differences in visual attention and think-aloud protocols of air traffic situation awareness. Situation awareness should be central to successful air traffic control (ATC) performance (Endsley, 1995). The objective of this research was to advance our understanding of controller expertise and cognitive process in ATC situations varying with the demand of workload.

In this study, eye-tracking and protocol analyses were executed since the eye movements relating to think-aloud protocols should serve as effective clues to understand cognitive process of controller performance (Ware & Mikaelian, 1987; Ericsson & Charness, 1994).

Experiment 1

To examine controllers' perceptual information processing pattern as a function of expertise and complexity of traffic flow, we employed a 3 x 2 mixed factorial design with a between-participants variable of controller expertise (expert, intermediate, novice) and a within-participants variables of complexity of traffic flow (simple, complex). The ATC situations were represented with radar screen pictures, which consisted of four situations varying with complexity of traffic flow.

Methods

Seventeen field controllers from Seoul Approach Control Center participated in this experiment. The participants fell into three groups, each with different levels of ATC experience: 4 experts, 8 intermediates, and 5 novices.

Experiment procedure was divided into two stages; preparative stage and executive stage. In preparative stage, participants put on an eyetracker designed to record participants' eye movements. In executive stage, participants

were to view four radar screen pictures each for 30 seconds. The procedure was repeated four times per participant in accordance with four screen pictures.

Results and Discussion

The Number of Fixations. As shown in Figure 1, there was a significant interaction between expertise and complexity of traffic flow, $F(2,14) = 3.773$, $p < .05$, $\eta^2 = .350$. For experts, the number of fixations was smaller for the complex traffic flow than for the simple traffic flow. For novices, in contrast, the number of fixations was greater for the complex traffic flow than for the simple traffic flow.

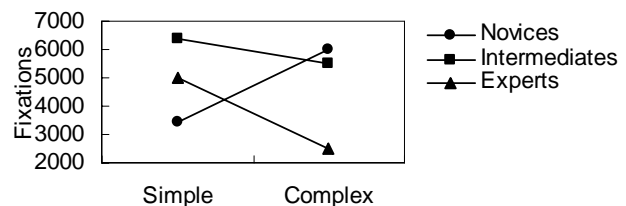


Figure 1: Average number of fixations.

The Duration of Each Fixation. A significant interaction between expertise and complexity of traffic flow was found, $F(2,14) = 6.328$, $p < .05$, $\eta^2 = .475$. As shown in Figure 2, the expert group spent more time gazing at targets in the complex traffic flow than that in the simple traffic flow whereas the novice group spent less time gazing at targets in the complex traffic flow than that in the simple traffic flow.

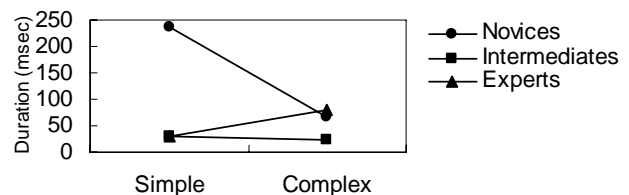


Figure 2: Average duration of each fixation.

The Distance of Saccades between Fixations. There was a significant effect of expertise on the distance of saccades, $F(2,14) = 3.452$, $p = .06$, $\eta^2 = .330$. And a significant interaction between expertise and complexity of traffic flow was confirmed, $F(2,14) = 7.148$, $p < .05$, $\eta^2 = .505$. The expert group showed an increased distance of saccades in the complex traffic flow, which was not the case for the other groups, as shown in Figure 3.

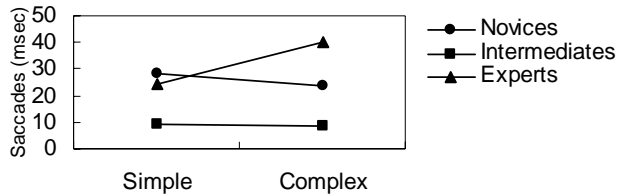


Figure 3: The average distance of saccades between fixations.

Experts' perceptual pattern suggests that they might use a kind of attention strategy to selectively focus on targets diagnostic for their situation awareness. The strategy can be understood as an efficient way of mental resource management, which was critical in situation awareness and decision making under high workload (Finkelman & Kirschner, 1980).

Experiment 2

The goal of Experiment 2 was to understand air traffic controller expertise in its cognitive and meta-cognitive aspects through protocol analyses.

Methods

While participants' eye movements were being recorded in Experiment 1, they were asked to think aloud. After completing the situation awareness task, participants were given a recall task delayed with an intervening task. Then, we had an interview with them about perceived problems and solutions from the situation reconstructed by them. The coding scheme used in this experiment was the same as that used by Seamster et al. (1993), in which cognitive activities involved in ATC were classified into Strategy Model, Task Model, and Mental Model. The protocols recorded were arranged in sentence level and then coded in terms of frequencies to score report rate. In a recall task, recall performance was scored by the number of tracks recollected.

Results and Discussion

The analysis of report rates scored on the basis of Seamster et al.'s (1993) model showed an expertise effect on Strategy Model and Task Model, but not on Mental Model

Strategy Model Analysis. As a result of protocol analysis using this coding scheme, as shown in Figure 4, there was an expertise effect on report rate for workload management, $F(2,14) = 5.988, p < .05, \eta^2 = .461$. Overall the expert group reported about workload management strategy at a high rate.

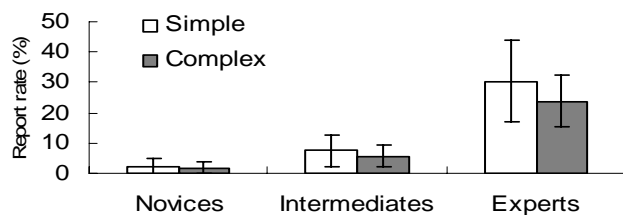


Figure 4: Report rate for workload management.

Task Model Analysis. There was an expertise effect on report rate for Task Model, $F(2,14) = 4.1404, p < .05, \eta^2 = .370$. As shown in Figure 5, the intermediate group reported more about tasks than the other groups. This result suggested that the intermediate group was more likely to

think about the control to be performed for each target during the situation awareness task even within 30 seconds time limit.

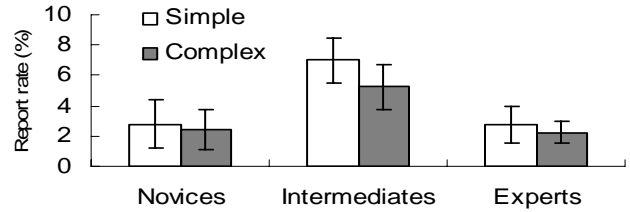


Figure 5: Report rate of task model.

Recall task. There was an effect of complexity of traffic flow on the delayed-recall performance, $F(1,14) = 9.944, p < .05, \eta^2 = .415$. As shown in Figure 6, this pattern of results might occur because the simple condition requires only monitoring the current state of air traffic but the complex condition requires in-depth processing of traffic flow to predict the near future state of air traffic and plan actions.

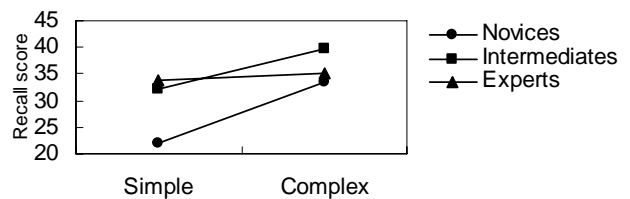


Figure 6: Recall task scores.

GENERAL DISCUSSION

In this study, the eye-tracking and protocol data allowed us to understand how controllers process information as a function of their expertise and air traffic situation complexity. The processing pattern of experts was different from novice and intermediate controllers as complexity of situation varied. When air traffic situations involved a high potential risk as in the complex traffic flow condition, experts decreased the number of aircraft to attend to and increase the processing time for each object as well as the distance of saccades between the objects. The result that expert controllers concentrated only on the smaller number of critical features implicates their use of selective attention strategies. The protocol analysis results of using strategies to reduce workloads also supported the use of selective attention strategies applied in a meta-cognitive level.

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